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AN EXTINGUISHER TO QUENCH PROPELLANT FIRES

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Details are given on a novel fire extinguisher which has been used successfully to extinguish propellant fires. The extinguishing fluid is driven by an explosive charge. This allows complete quenching of propellant fires in as short a time as 5 milliseconds after activation of the extinguisher. The effect of certain variables on the success of the extinguishing experiments are reported. These variables are: volume of extinguishing agent; weight of explosive; time delay between start of fire and activation of the device; and the composition of the extinguishing fluid. (Keywords:-)

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1. INTRODUCTION

It has long been recognized that propellant fires are extremely difficult to extinquish once they are started. Our previous work on this problem[1,2,3] has shown that in order to quench propellant fires successfully, it is necessary to respond to the fire as quickly as possible. The extinguishing agent should be delivered to the fire in the sub-second time frame. It is also thought to be very important to apply the bulk of the extinguishing agent to the fire in as short a time frame as possible.

There are several detectors available[4] which can respond to fire and send out a signal to an extinguisher in milliseconds. Very fast acting solenoid valves on Halon 1301-type pressurized bottles can open and allow 2.7kg (six pounds) of fluid to pass through the valve in approximately 100 milliseconds.[5] Test results[5] indicate that this is adequate to extinguish the fuel mist fireball caused by a shaped charge jet passing through the fuel cell of a vehicle.

Evidence[6] strongly favors a gas phase interruption of a free radical chain as the primary means by which Halon 1301 quenches hydrocarbon fires. Unfortunately, this mechanism is not available in the case of propellant fires where each grain of propellant carries both fuel and oxidizer which can react in both the solid and gas phases. It has been shown that Halon 1301, by itself, is not suitable for extinguishing propellant fires.[1] Other fire extinguishing agents are required if we are to quench propellant fires in the millisecond time frame. Water based foam agents were used with some success against propellant fires; however, there was a problem in delivering the agent to the site of the fire in a short enough time to fully quench the propellant fire. At times, the fire appeared to be extinguished, but re-ignition occurred.[1]. It was felt that if all the available extinguishing agents could he put onto the fire in a very short time, the probability of completely quenching the fire would be improved.

2. A NEW TYPE OF FIRE EXTINGUISHER

In fuel-air explosive studies, a small explosive charge is often submerged right in the liquid fuel which is to be disseminated.[7] When the small charge functions, the liquid is dispersed into the air. This appraoch was tried with a water based foam fire extinguishing liquid. It was thought that an explosive charge would drive the liquid to the site of the fire more quickly than conventional means could achieve. A schematic of the fire extinguishing concept is given in Figure 1.

A plastic container, volume about four liters, was filled almost completely with a solution of 61% antifreeze,30% water, and 9% foaming agent. A 30cm length of Prima Cord® containing 2.6 grams of explosive was almost entirely submerged in the liquid. A small detonator was attached to the end of the Prima Cord® which extended out of the liquid. A high speed

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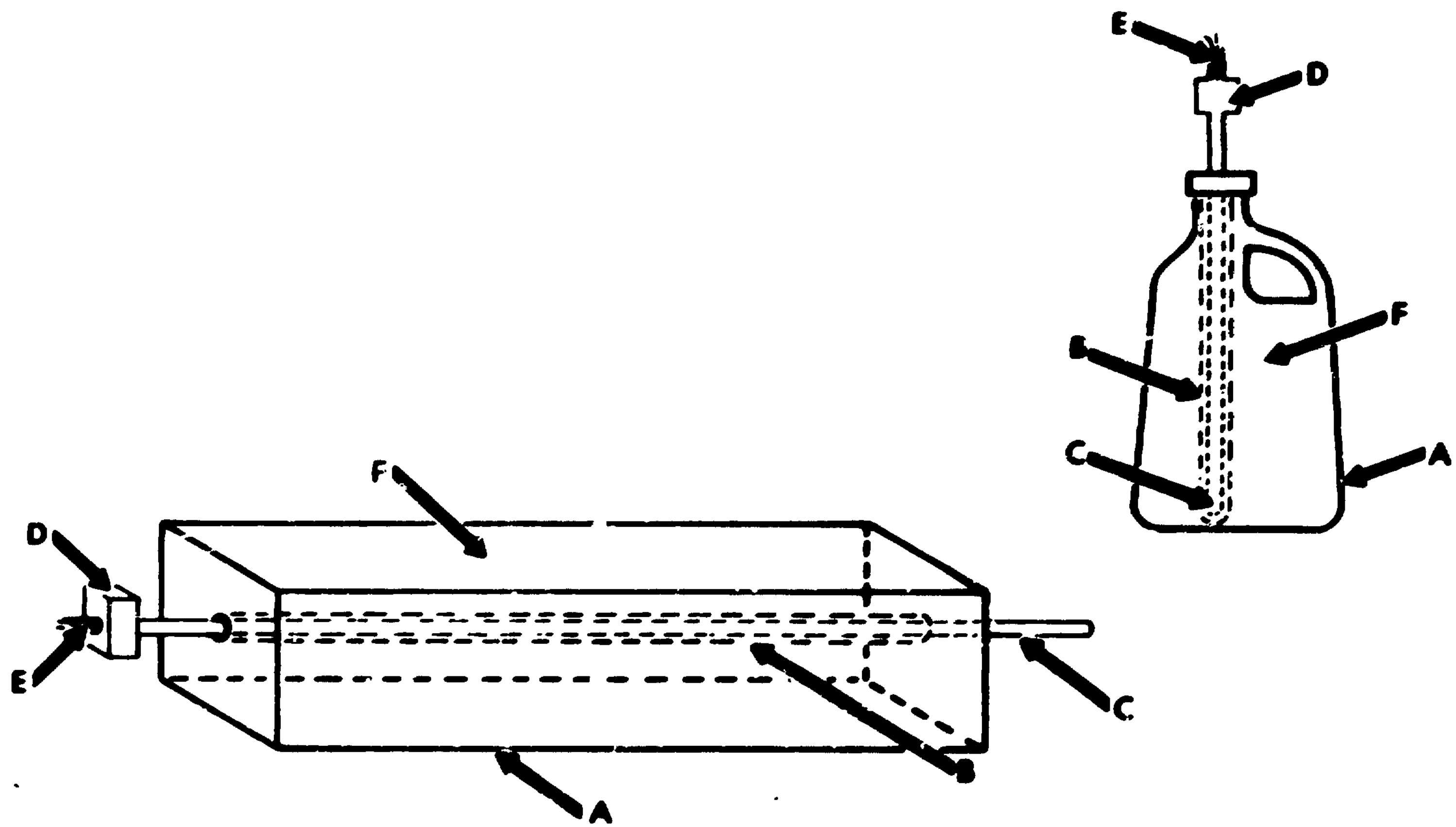

A - Wall of Container
B - Agent-Proof Tube Entire Length of Container
C - Detonating Cord Inside Tube "B"
D - Detonator to Initiate Detonating Cord "C"
E - Electrical Leads to Control Device
F - Fire Extinguishing Agent Inside Container

Figure 1. Sketch of Device for Rapidly Dispensing Fire Extinguishing Agents

framing camera (500 frames per second) was used to record the event when the detonator functioned. Inspection of the film showed that the liquid was driven 1 meter in 6 milliseconds. Moreover, all of the liquid was driven out as a unit. In a matter of a few milliseconds, all four liters of liquid were dispensed from the plastic container which broke into three large pieces. One piece (which traveled the farthest) was recovered 10 meters from the detonation site. The liquid was driven out horizontally by the linear charge. Little fluid was driven up or down. The fluid behaved somewhat like an expanding cylinder. A schematic of the test set-up is given in Figure 2. It should be mentioned that in another, similar test utilizing one-half the explosive charge, the container simply split open. No fragments were formed. The split-open container was recovered at the detonation site. An examination of the film record showed that the liquid traveled 2 meters in 34 milliseconds.

It was felt that this would be a viable way of delivering a large quantity of liquid to a fire in a very short time. The quantity of foam formed was not as great as previously observed when using pressurized fire extinguishers.[1] Therefore, it was necessary to increase the concentation of foaming agents to allow the extinguishant to cover the same amount of material as could be covered using a pressurized extinguisher.

Unlike the discharge from a pressurized extinguisher (through a nozzle) where the leading edge of a liquid stream may get to a fire quickly, the explosive system can deliver all its contents in just a few milliseconds. The liquid can be focused by suitable placement of the explosive charge in the liquid; by the shape of the container; or by placing the container against a wall or corner. The container may also be scored for ease of breaking and for controlling the location of the rupture of the extinguisher. It is even possible to construct a steel container with one weak (plastic) section. All liquid will be ejected through this section.

It should be mentioned that when extinguishers made of plexiglass (6 mm thick) were used, many plexiglass fragments were formed. Some fragments were recovered over 7 meters from the test site. These fragments could present a problem if a plexiglass extinguisher were to be used near personnel.

3. USES OF THE NEW EXTINGUISHER

Past experience[1] has shown that when using conventional (pressurized) extinguishers, it is critical to respond to a propellant fire with the extinguishing agent as quickly as possible; certainly in less than one second. In order to establish that the explosive extinguisher was indeed superior to a conventional extinguisher, an experiment was conducted in which a long time delay was used. A propellant fire involving 23kg of propellant was allowed to grow to its maximum intensity before the explosive extinguisher functioned. The extinguisher was able to quench the fire. Details of the experiment are in Table 1. A schematic of the set-up is presented in Figure 3.

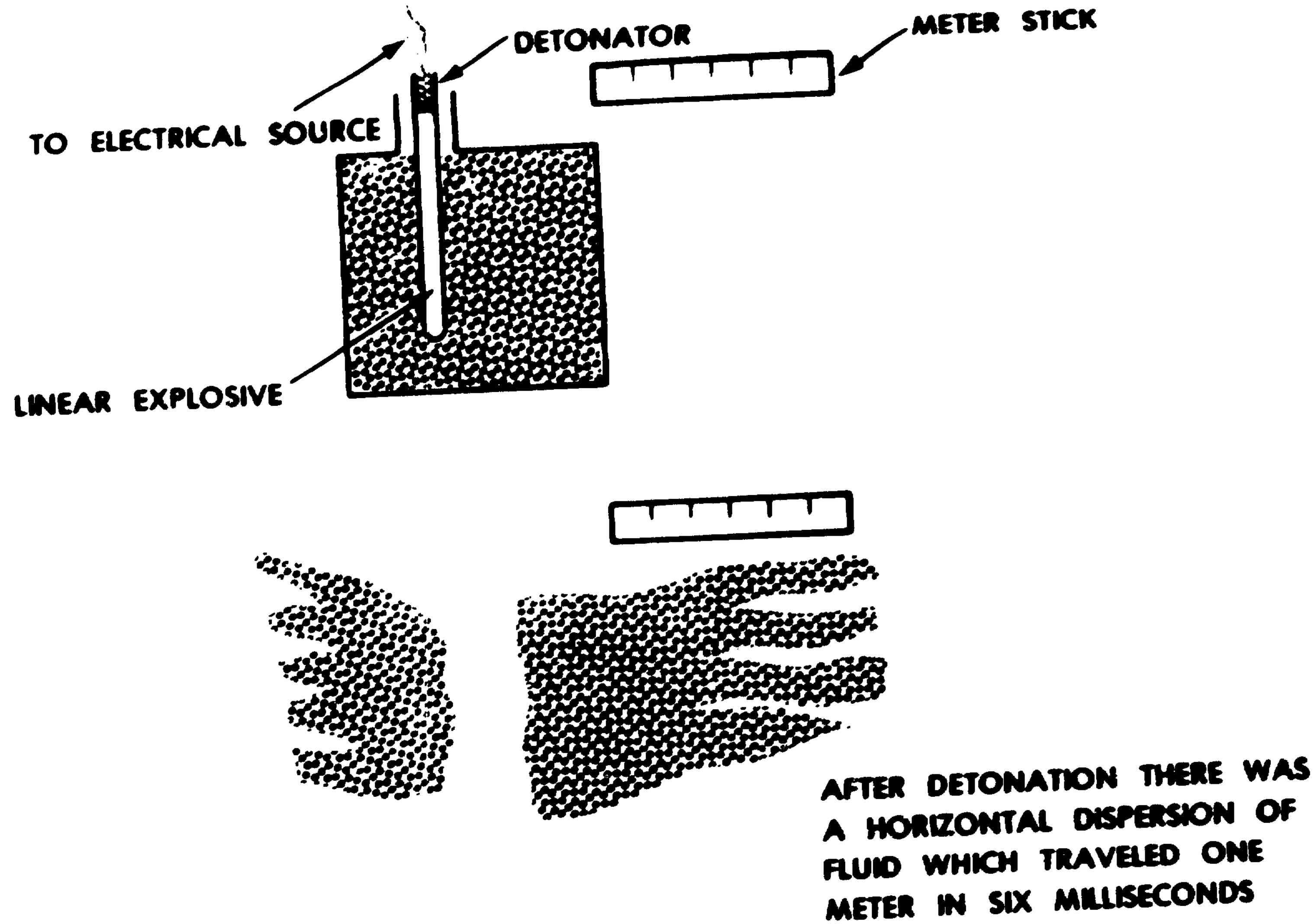

Figure 2. Test of the Explosive Extinguisher

TABLE 1. Details of the Long Time Delay Fire Extinguishing Experiment

Experimental Set-up	Steel box, top and front open; 1m long, 1-1/2m wide, 1m high. Propellant and extinguisher both inside this box.
Propellant	23kg (50 Pounds) M30
Extinguisher	Box, 5 sides steel, 1 side plastic, containing approximately 34 liters (9 gallons) of 20% foam solution in water. Liquid driven by 7.8 grams of explosive.
Time Delay	Extinguisher functioned 8 seconds after ignition of propellant.
State of Fire	Flames were 6 meters (20 feet) into the air when the extinguisher functioned.
Method of Functioning	Heat from the fire set off the heat sensitive explosive used in the detonators. This initiated the 7.8 grams of explosive in the Prima Cord®.
Fire Out Time	Immediate; no more than a few milliseconds.
Amount of Propellant Remaining	11kg (24 Pounds)

This test marked the first time that it was possible to extinguish a propellant fire after it had achieved a high intensity. We had been able to extinguish only much smaller propellant fires using pressurized extinguishers containing water-foam solutions. The reason this test was successful was that the fire was overwhelmed by putting all the extinguishing agent onto the propellant at one time.

Tests were then conducted to give a comparison of the ability of the exploding extinguisher to quench a propellant fire versus a conventional pressurized extinguisher attacking a similar fire. The tests were carried out in a 1,330 liter (47 cubic foot) steel container open on the top. Test conditions and results are presented in Table 2.

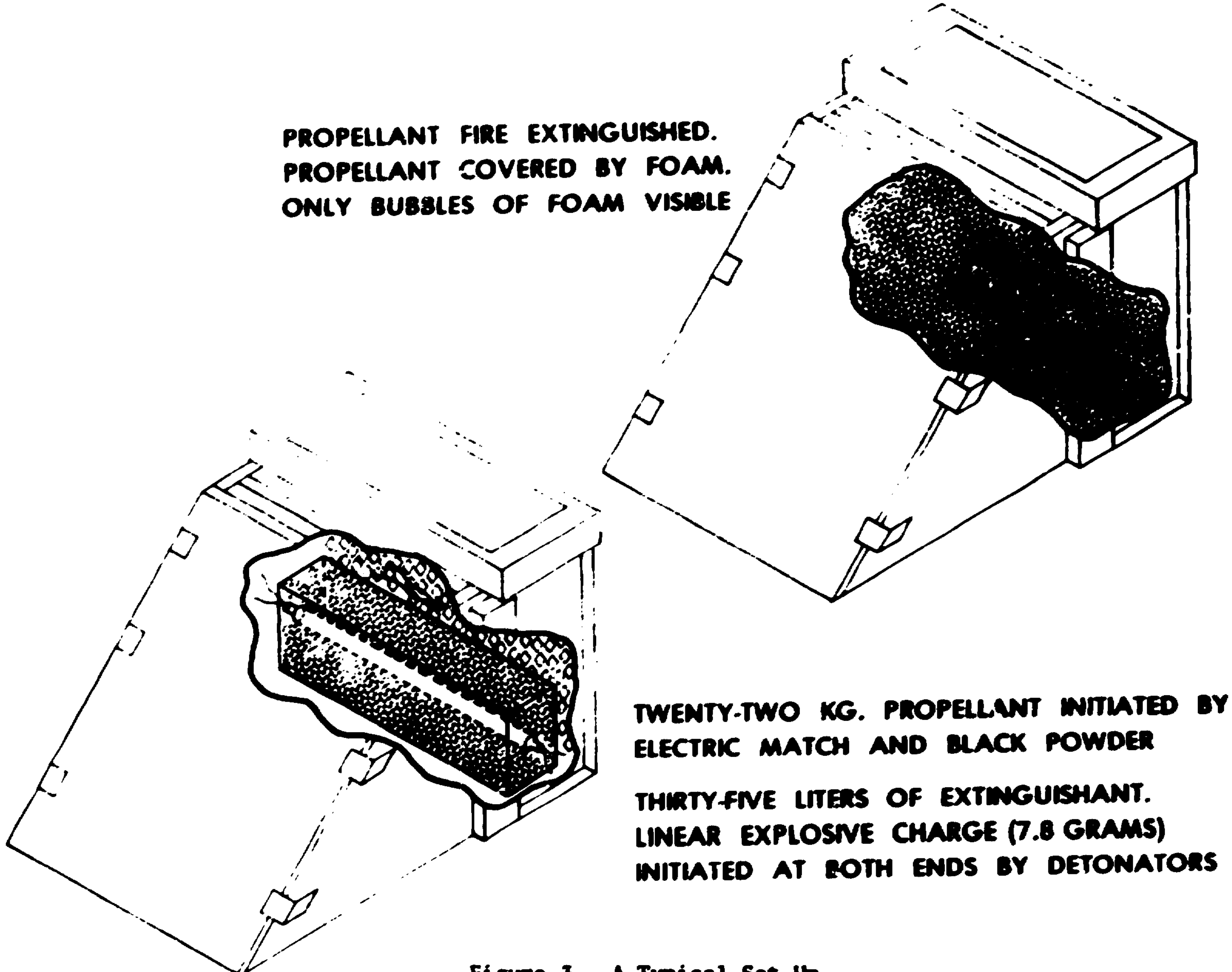

Figure 3. A Typical Set-Up

TABLE 2. A Comparison of Two Fire Extinguishers

	Conventional Extinguisher	Exploding Extinguisher
Test Set-up	1,330 liter steel container, top open.	Same Container
Extinguishers	2 pressurized, each containing 38 liters (10 gallons) of 25% foaming agent plus additives in water at 1.7MPa (250psi). 2 hoses, each 44mm id carried fluid from the 38mm id valves of extinguishers into the steel container.	4 exploding extinguishers, each containing 9.5 liters (2.5 gallons) of 25% foaming agent plus additives in water. 1 extinguisher on floor of container, 2 against sides of container, and 1 over propellant sample. Each extinguisher contained 28 grams of explosive (Prima Cord®).
Propellant	45kg (100 Pounds) of M30	44kg (97 Pounds) of Mixed Propellants
Ignition Source	Electric Match Plus Black Powder	Same
Time Delay	2 seconds; 24 volt pulse sent to solenoid valve of extinguishers.	250 milliseconds; ultraviolet fire detector system initiated detonators which initiated Prima Cord® of extinguishers.
Results	Propellant continued to burn, but inefficiently, with no flame. Large quantity of smoke emitted. Most of liquid appeared to boil off as fast as it was delivered to the fire. When fire was finally extinguished, about 10kg (22 pounds) of original 45kg (100 pounds) remained.	Fire completely out less than 5 milliseconds after extinguishers activated. Virtually all propellant recovered. Much of propellant thrown out of steel container when extinguishers functioned.
Conclusions	If liquid extinguishing agent can be delivered to propellant fire fast enough, it will eliminate flame and remove much of the heat generated by the burning propellant.	Exploding extinguishers can quench a propellant fire much more quickly and thoroughly than any method which delivers the extinguishant over a long period of time (seconds or longer). The fire is quenched in milliseconds. Since a single grain of propellant will burn for several seconds, it is clear that burning grains are being quenched completely.

A series of tests was conducted to determine the size of exploding extinguisher required to quench propellant fires of various intensities. Only one extinguisher was used for each test. The size of the extinguisher and amount of explosive used in the extinguisher were varied. All fires were initiated by an electric match and black powder. The intensities of the fires were controlled by the amount of propellant used and the time delay between initiation of the fire and functioning of the extinguisher. All tests were conducted in a metal container of approximately 600 liter capacity. The top and front of the container were removable. Data from these tests (both successful and unsuccessful tries) are presented in Table 3.

4. INTERPRETATION OF RESULTS

The data of Table 3 were examined in an effort to determine which of the measured parameters actually controlled the success or failure of the extinguishing experiments. The parameters assumed to be important are given in Table 4. These parameters are:

a. Amount of propellant.

b. Amount of extinguishing agent.

c. Composition of the extinguishing agent.

d. Amount of explosive used to drive the agent.

e. Time delay between ignition of propellant and activation of extinguisher.

The size of the test chamber was not included as a parameter since it was not varied in these experiments. These tests were all carried out in the 600 liter fixture. It is reasonable to think that there must be a size effect since the liquid must be delivered to all parts of the container to ensure the complete quenching of the propellant fire.

The several combinations in which the parameters were examined are presented in Table 5. It can be seen from the table that a valid correlation of parameters with successful extinguishments involved the product of the volume of agent and the weight of explosive used to drive the agent. A low value of this product correlated with failure to extinguish the propellant fires. A high value of this product correlated with succesful suppression of the fires. A second valid correlation was found using the same product as the first correlation (volume of agent multiplied by weight of explosive) divided by the weight of propellant involved in each fire. However, there was only a minor variation in the amount of propellant used in the experiments. Only one test involved a small (6.8kg) amount of propellant. All other tests involved 20.8 to 22.7kg of propellant. The importance of the weight of propellant cannot be assertained from these experiments.

It was quite surprising to find that the time delay between ignition of the propellant and activation of the extinguisher was not a critical factor in determining the success or failure of the fire extinguishing tests.

TABLE 3. Results of Propellant Fire Extinguishing Tests Conducted in a 600 Liter Container

Propellant	Extinguisher	Delay	Results
6.4kg loose M30; 3 aluminum tubes w/ends sealed w/manila paper to simulate combustible cartridge cases.	19 liters of a 20% foaming agent in water driven by 13 grams of explosive.	100ms	Fire Out Immediately
6.4kg loose M30; 2 aluminum tubes on sides, each containing 5.4kg M30 plus pieces of combustible cartridge cases. One end of each tube open, other end sealed w/manila paper. One aluminum tube standing, containing 5.4kg of M30 plus pieces of broken combustible cartridge case.	19 liters of a 20% foaming agent in water driven by 13 grams of explosive.	100ms	Fire Out Immediately
6.8kg of loose M30; 1 aluminum tube upright, open on top, containing 4.5kg of diegel RP propellant 7.6cm down from top. One aluminum tube, upright, containing 4.5kg of diegel RP propellant, sealed w/manila paper; propellant 7.6cm down from top. One aluminum tube on its side, 3kg of diegel RP propellant and 2kg of M30, open on top.	19 liters of a 20% foaming agent in water driven by 13 grams of explosive.	44ms	Fire Out Immediately, But Smoke For 2-3 Seconds
22.7kg of Loose M30	13 liters of 15% foaming agent in water driven by 8 grams of explosive.	4sec	Did Not Quench Fire
22.7kg of Loose M30	34 liters of 25% foaming agent in water driven by 7.8 grams of explosive.	8sec	Fire Out Immediately

TABLE 3. Results of Propellant Fire Extinguishing Tests Conducted in a 600 Liter Container (Cont)

Propellant	Extinguisher	Delay	Results
22.7kg of Loose M30	34 liters of 15% foaming agent in water driven by 7.8 grams of explosive.	100ms	Fire Out Immediately
22.7kg of Loose M30	34 liters of 15% foaming agent in water driven by 7.8 grams of explosive.	500ms	Fire Appeared Out; Lots of White Smoke
22.7kg of Loose M30	30 liters of 25% foaming agent in water, driven by 7.8 grams of explosive.	20sec	Fire Out Immediately (Most of M30 had burned before the extinguisher was activated.)
22.7kg of Loose M30	30 liters of 25% foaming agent in water driven by 7.8 grams of explosive.	1sec	Fire Appeared Out; Reignition
22.7kg of Loose M30	30 liters of 25% foaming agent in water driven by 7.8 grams of explosive.	50ms	Fire Out Immediately
22.7kg of Loose M30	23 liters of 17% foaming agent in water driven by 6.9 grams of explosive.	100ms	Fire Appeared Out; Reignition
22.7kg of Loose M30	19 liters of 20% foaming agent in water driven by 6.05 grams of explosive.	1.5sec	Fire Not Quenched
22.7kg of Loose M30	19 liters of 25% foaming agent in water, driven by 5.2 grams of explosive.	100ms	Fire Appeared Out; Reignition; Lots of White Smoke

TABLE 4. Variable Conditions Used in Tests of Exploding Extinguisher

Amount of Propellant (kg)	Amount of Extinguishing Fluid (Liters)	Volume % of Foaming Agent	Weight of Explosive (Grams)	Time Delay Between Propellant Ignition and Activation of Extinguisher (Milliseconds)	Was Fire Quenched?
6.4	19	20	13	100	Yes
22.6	19	20	13	100	Yes
20.8	19	20	13	44	Yes
22.7	13	15	8	4000	No
22.7	34	25	7.8	8000	Yes
22.7	34	15	7.8	100	Yes
22.7	34	15	7.8	500	Yes
22.7	30	25	7.8	20000	Yes
22.7	30	25	7.8	1000	No
22.7	30	25	7.8	50	Yes
22.7	19	20	6.05	1500	No
22.7	19	25	5.2	100	No

TABLE 5. Possible Useful Criteria for Correlating Experimental Variables With Test Results

A		B		C	
Weight of Propellant (kg)	Fire Quenched?	Volume of Extinguishant (Liters)	Fire Quenched?	Time Delay Between Propellant Ignition & Activation of Extinguishant (ms)	Fire Quenched?
6.4	Yes	13	No	44	Yes
20.8	Yes	19	Yes	50	Yes
22.6	Yes	19	Yes	100	Yes
22.7	Yes	19	Yes	100	Yes
22.7	Yes	19	No	100	Yes
22.7	Yes	19	No	100	No
22.7	Yes	23	No	100	No
22.7	Yes	30	Yes	500	Yes
22.7	No	30	No	1000	No
22.7	No	30	Yes	1500	No
22.7	No	34	Yes	4000	No
22.7	No	34	Yes	8000	Yes
22.7	No	34	Yes	20000	Yes

TABLE 5. Possible Useful Criteria for Correlating Experimental Variables With Test Results (Cont)

D		E	
Weight of Explosive (Grams)	Fire Quenched?	(Weight of Explosive (Grams)) X (Volume of Extinguishant (Liters))	Fire Quenched?
5.2	No	99	No
6.05	No	104	No
6.9	No	115	Nc
7.8	Yes	159	No
7.8	No	234	No
7.8	Yes	234	Yes
7.8	Yes	234	Yes
7.8	Yes	247	Yes
7.8	Yes	247	Yes
8	No	247	Yes
13	Yes	265	Yes
13	Yes	265	Yes
13	Yes	265	Yes

TABLE 5. Possible Useful Criteria for Correlating Experimental Variables With Test Results (Cont)

F = (Weight of Explosive (Grams)) X (Volume of Extinguishant (Liters)) ÷ (Time Delay (ms))	Fire Quenched?
12	Yes
26	No
33	No
77	No
234	No
530	Yes
990	No
1590	No
2470	Yes
2470	Yes
2650	Yes
4680	Yes
5614	Yes

TABLE 5. Possible Useful Criteria for Correlating Experimental Variables With Test Results (Cont)

G: (Weight of Explosive (Grams)) X (Volume of Extinguishant (Liters)) ÷ (Weight of Propellant (kg))	Fire Quenched?
4.4	No
4.6	No
5.1	No
7.0	No
10	No
10	Yes
10	Yes
11	Yes
11.8	Yes
12	Yes
12	Yes
12	Yes
39	Yes

TABLE 5. Possible Useful Criteria for Correlating Experimental Variables With Test Results (Cont)

H: (Weight of Explosive (Grams)) X (Volume of Extinguishant (Liters)) X (Volume % of Foaming Agent) ÷ (Weight of Propellant (kg))	Fire Quenched?
69	No
102	No
110	No
119	No
180	Yes
180	Yes
220	Yes
236	Yes
250	No
250	Yes
250	Yes
300	Yes
780	Yes

Previous work with pressurized extinguishers had shown that the time delay was important. Yet the time delay proved to be unimportant in the case of the exploding extinguishers.

5. RATIONALIZATION OF A MODEL

A fire involving over 20kg of propellant (most of the fires reported in Table 3 are of this size) generates about 3000kcal of heat each second. A fire of this intensity can vaporize over five liters per second of a water-based extinguishing agent. Our past experience[1] with fires of this size demonstrated that such fires are very difficult to extinguish using conventional pressurized extinguishers. Yet propellant fires of this size, even at maximum intensity, were quenched using exploding extinguishers. This may be due to the fact that this type extinguisher delivers all of its liquid as a unit to the fire within milliseconds after activation of the extinguisher. A 20kg propellant fire cannot generate heat rapidly enough to boil off the liquid as it is delivered to the fire.

It is reasonable to expect that all liquid will be delivered to the fire within a time-frame of 50 milliseconds. A large propellant fire, generating 3000 kcal per second, gives off only 150kcal in 50 milliseconds. This heat is adequate to vaporize only about 300 milliliters of the liquid as the liquid is delivered to the propellant fire. This small loss of agent to vaporization does not prevent quenching of the fire. Evidence from films shows that the propellant fires can be completely extinguished in just a few milliseconds when all liquid is delivered as a unit. All propellant grains must be drenched at the same time to insure a successful extinguishment. If even a few burning grains are not quenched, combustion will be transfered to the other, non-burning grains as the extinguishant drains off them. Since all grains must be covered by extinguishant, it apparently does not matter how many grains are burning when the extinguisher is activated. Therefore, the extinguisher can quench a fully involved fire as well as a smaller fire.

6. CONCLUSIONS

It has been demonstrated that the exploding extinguisher is capable of quenching large propellant fires within milliseconds after activation.

In several successful tests, approximately four liters of liquid were used for each gram of explosive employed. Therefore, large quantities of explosive are not required even for extinguishers containing large volumes of liquid.

Relatively large concentrations of foaming agent (20-25% by volume) are required to achieve a reasonable amount of foam in the final product.

Large concentrations (over 60% by volume) of ethyleneglycol-type commercial antifreeze may be used in the liquid.

Aiming of the liquid may be achieved by suitable geometry of the container or simply by proper placement of the explosive charge.

In a given size container with a constant amount of propellant, the critical factors in extinguishing a propellant fire are the amount of liquid and the amount of the explosive charge. The time of response is not critical in determining whether or not the fire is quenched.

Since this method of extinguishing a fire can quench individual grains of propellant while they are burning, it may be possible to apply this approach to quenching fires associated with damaged rocket motors which usually have single (but very large and energetic) grains of propellant.

The exploding extinguisher may be useful for extinguishing fires involving incendiary materials since a successful experiment depends on completely drenching the mound of burning propellant. This drenching may be sufficient to extinguish even highly energetic incendiary materials.

7. FUTURE WORK

A subsequent report on the use of exploding extinguishers will deal with their ability to rapidly quench fires initiated by shaped charge jet attack on ammunition. Rapidly quenching ammunition fires in both crew compartments and separate ammunition storage compartments will be addressed. Tests on an actual vehicle as well as a generic vehicle will be reported.

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